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Further investigation of a contactless patient-electrode interface of an Electrical Impedance Mammography system

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Abstract. The Sussex Mk4 Electrical Impedance Mammography (EIM) system is a novel instrument, designed for the detection of early breast cancer, based upon Electrical Impedance Tomography (EIT). Many innovations in the field have been incorporated in the design improving both signal distribution and response. This paper investigates the behaviour of the contactless patient-electrode interface. The interface was studied in detail using phantom and healthy volunteer, *in-vivo*, data. Our findings show the necessity for the careful design of electrode enclosure so that the response of the system is not affected by the unpredictable positioning of the breast; it closely mimics those conditions seen when using the phantom. The paper includes a number of possible designs and their individual characteristics. In addition an explanation on the unanticipated effects and solutions for such are described.

1. Introduction

Studies have shown that a steady decrease of $2.0\% - 3.2\%$ in breast cancer related death rates per year since 1990 can be attributed to improvements in breast cancer treatments and early detection [1]. Electrical Impedance Mammography (EIM) has been recognized as a possible diagnostic tool for early breast cancer detection. By providing a spatial map of the electrical impedance distribution of the breast tissue, EIT can provide a non-invasive and non-ionizing screening method [2]. EIM has already been suggested as an adjunct to better established screening techniques [3].

One of the main challenges of EIT technology is that of the interface between patients and electrodes. The contact impedance and the current density at the contact point are both high, and any variability at this point will cause abnormal measurements [4]. Any such 'drift', especially if it occurs between measurement frames, is known to be responsible for artifacts appearing in the reconstructed conductivity images [5]. This effect is even more pronounced in absolute imaging, as the forward solution can be heavily dependent on the electrode-skin contact impedances, and other geometric factors [6][7].

Wang *et al.* [8] showed that a system whereby direct contact of the electrodes with the skin is avoided can result in significantly reduced artifacts, and also assist in the repeatability of EIT testing. The current paper presents further investigation into the use of this contactless interface, especially when applied to *in-vivo* studies of the human breast utilizing a planar array of electrodes. We will show how patient movement can negatively affect measurements, if proper care is not taken for the design of the electrode plate.

2. The Mk4 'Wet' Electrode Interface

The term 'wet' electrode, first coined in [8] denotes the constant existence of an intermediary contact medium, e.g. saline, between the electrode and the patient. Conduction of the current is then only ionic, not galvanic. Assuming the measurements are carried out in a tank, this can be achieved by embedding, or in-setting, the electrodes by a very shallow ($\sim 2mm$) depth into the electrode support structure, effectively forming an electrode cavity. Saline is used to fill up the tank before the test is carried out, and hence offer a uniform buffer medium between skin and electrode. In figure 1 is shown the implementation of this concept in the Sussex Mk4 EIM system [9], which utilizes a planar electrode array.

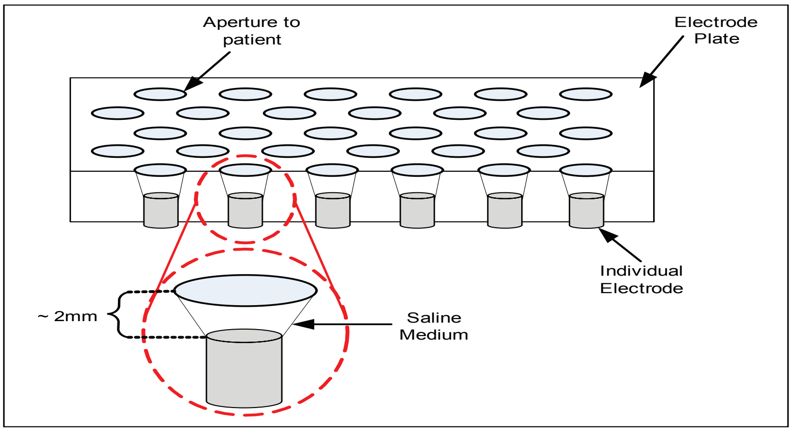

Figure 1. The Sussex Mk4 EIM planar electrode array, showing detail of the 'wet' electrode interface

The electrode plate lies at the bottom of a saline-filled tank, and the patients position themselves in the prone position. The breast comes in contact with the electrode plate and is partially compressed. This spreads the breast tissue over a larger percentage of the electrode array, while at the same time decreases the distance between the chest wall and the electrodes, allowing for higher coverage of the breast volume by the measurement system.

3. Unforseen *In-Vivo* Effects

In-vivo tests were carried out on volunteer patients in the course of the calibration of the Mk4 system against real-life loading conditions. During these tests, artifacts were detected in the form of saturated measurements coupled with measurements at or below the noise floor (effectively non-responsive channels). These artifacts, it was concluded, were not caused by systematic errors, as occurrences of artifacts were registered at different channels between scans of breasts, and the amount of artifacts greatly varied between subjects. In figure 2 is shown the left breast of a healthy subject. The graph shows clear signs of saturation, mixed with non-measurements (measurements at 0V). This corrupt data dominates the back-projection image, obscuring the outline of the breast entirely. The image was reconstructed using a back-projection algorithm [10] for demonstration, as no reconstruction algorithm can handle such saturations and non-measurements.

4. Loss of Contact

The Mk4 system was tested using saline, non-biological, and agar phantoms as part of the calibration procedure. During these tests, no unexpected artifacts were noted. Our initial assumption was that the Mk4 current source suffered from oscillations due to heavy loading. We, hence, devised a phantom based on the design found in [11], representing a very high load compared to the expected range for adipose and stroma. The results of this particular phantom test did not exhibit any saturated measurements either (see figure 4), and hence the phantom (in blue) can clearly be differentiated from the surrounding saline

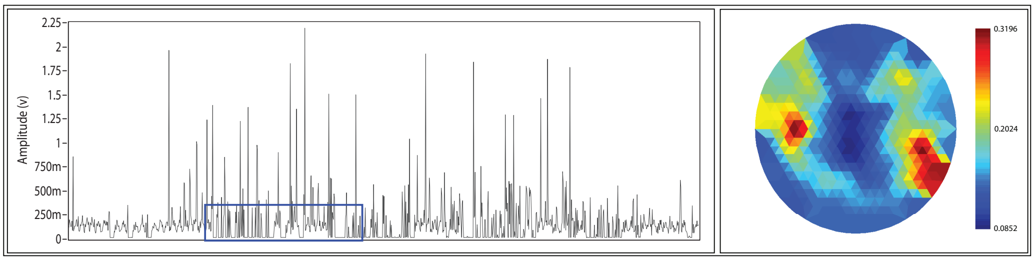

Figure 2. The breast scan shows clear signs of saturation that dominate the back-projection image. In the highlighted area, significant numbers of measurements were at 0V, effectively non-measurements.

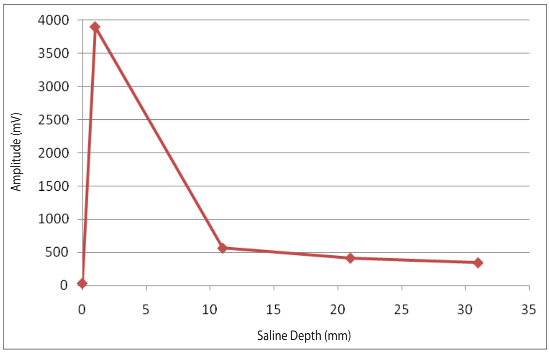

Figure 3. Measured values of single electrode combination against depth of saline.

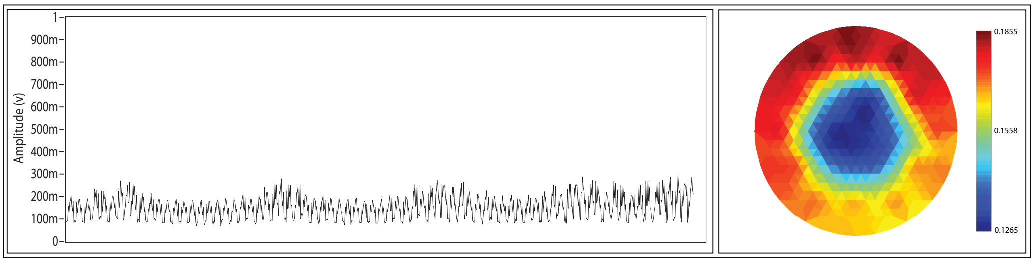

Figure 4. Agar phantom with conductivity structure similar to that of breast tissue, displaying no artifacts.

(in red). Further to this, when the system was tested with a very heavy load (that of a pure insulator), saturations were noted, as expected, but there were no non-measurements.

We next attempted to physically simulate a saturated or non-measurement channel. The depth of saline will normally affect the received output, due to variations in the loading. This test was now extended to verify the effect of lack of saline on the electrodes. Figure 3 shows that a marginal amount of saline ($2mm$) will exhibit saturation, while no saline will null the measurement by lack of loading of the current source.

The above tests led us to the conclusion that the positioning of the patient breast is responsible for the undesired effects. We have surmised that the skin of the patient is entering the electrode aperture and displacing the saline solution present, leaving minimal saline left, or none at all. A simple test of sealing a small number of electrodes was carried out to see if we could reproduce the desired effect, and the results were very similar to those in figure 2. We are concluding that, as agar phantoms are more solid than human skin, the agar would not enter the electrode cavity. Moreover, the 'wet' electrode testing in [8] was performed using the arm of a healthy male subject, again a more solid material.

5. Issue Resolution

Multiple ways of resolving the above mentioned problem can be suggested. One solution would be the use of a layer of material that is absorbent and conductive. The use of absorbent material, however, will introduce non-determinism in the measurements, as the structure of the material cannot be fully controlled, and hence its response cannot be fully modelled, and thus it is not under consideration. Alternatively, we can reduce the diameter of the electrodes significantly, so as to avoid any possibility of such unwanted effects. On the other hand, this would increase the difficulty and complexity (and cost) of producing both the electrodes and the interface.

The solution that was adopted at this stage was for the increase in the aperture size, and the further recessing of the electrodes (to $\sim 5mm$). Results of this test are shown in figure 5.

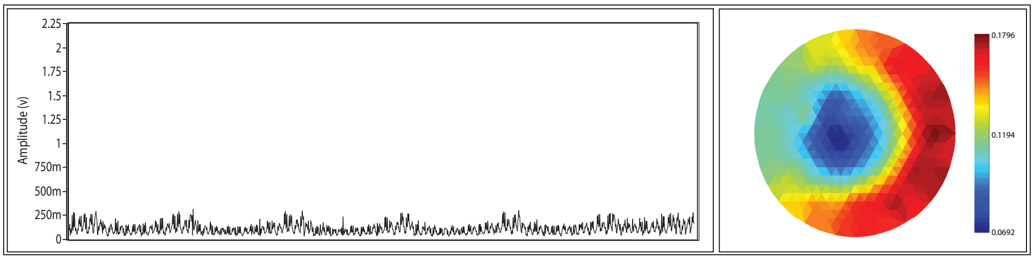

Figure 5. Scan of patient using different design of electrode plate, with further recessing. The breast can clearly be seen (blue in center and 9 o'clock position) surrounded by saline (red in 3 o'clock area).

6. Conclusion

Artifacts due to the electrode-patient interface have been one of the main challenges in EIT. Our research has shown that this is also the case with planar array of electrodes, even with recessed electrodes. The natural elasticity of breast tissue and patient movement can affect the contact impedance between patient and electrodes, leading to saturated channels and non-measurements. A simple solution has been found, but work is in progress for a more advanced solution that will not affect the detection depth.

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